

## HYDROXYL EMISSION AT HIGH LATITUDES

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*ABSTRACT: This paper presents the results of systematic observations of hydroxyl emission at the Loparskaya station ( $\phi = 68.3^{\circ}\text{N}$ ) during the winter periods in 1960-1963. The intensity of the hydroxyl emission at the Loparskaya station does not deviate considerably from the OH intensity at lower latitudes, and the rotation temperature is about  $20\text{-}40^{\circ}\text{K}$  higher than in the middle latitudes. During aurora displays, the intensity and the  $T_{\text{rot}}$  of the OH bands do not increase. In the winter months, the rotation temperature remains almost unchanged from year to year, and no decrease in the  $T_{\text{rot}}$  of the OH bands is observed during lower solar activity.*

Recently, there have appeared extensive and, in a number of cases, systematic materials on the hydroxyl emission of the upper atmosphere [1-5]; there have been a particularly large number of studies on the rotational temperature of the OH bands. There are less data on the intensity of the hydroxyl emission, which is obviously related to the limited number of observations, because of the instability of the weather. /22

The materials obtained show the great instability of the hydroxyl emission; the rotational temperature of the OH bands shows substantial seasonal and daily variations. According to the data in [4], the seasonal changes of the  $T_{\text{rot}}$  in the region  $\phi = 41.8^{\circ}\text{N}$  are  $\sim 75^{\circ}\text{K}$ , with a maximum during the winter. In the study in [5] (Yakutsk,  $\phi = 62^{\circ}$ ), the  $T_{\text{rot}}$  also increases in the winter, and the amplitude of the oscillations is about  $60^{\circ}\text{K}$ . Somewhat smaller values for the seasonal variations of the  $T_{\text{rot}}$  ( $\sim 30^{\circ}\text{K}$ ) were obtained in [1] ( $\phi = 42.6^{\circ}$ ). The intensity of the hydroxyl emission, which can change by one order, shows even more significant variations [3]. A similar picture is observed at other stations [4, 5]. Moreover, there are observed changes in the relative intensities of OH bands with different original levels [4, 5], while the bands with lower values of  $\nu'$  show lower values of  $T_{\text{rot}}$ . A number of data, although they are scarce, show rather convincingly the increase in  $T_{\text{rot}}$  with latitude [2, 6, 7]. However, the measurements conducted in [8] contradict these results. Even more contradictory results were obtained in relation to the dependence of  $T_{\text{rot}}$  on the intensity of the corresponding bands. At relatively high latitudes (Yakutsk,  $\phi = 62^{\circ}\text{N}$ ), for temperatures higher than

250° K, there is observed a clear relationship between  $I$  (OH) and  $T_{\text{rot}}$  [5]; at middle latitudes, this relationship is less clearly pronounced (Zvenigorod,  $\phi = 56^\circ\text{N}$  [13]); at lower latitudes (Abastumani,  $\phi = 41.8^\circ\text{N}$  [9]), there is again observed a relationship between  $I$  (OH) and  $T_{\text{rot}}$ .

Thus, the data we have show the complexity of the behavior of hydroxyl emission. It is of considerable interest to study the properties of OH in an auroral zone, where as a rule, the atmosphere is agitated by a direct invasion of corpuscles, as a result of which we can anticipate that the atmosphere will be heated up at high latitudes, and that the concentration of the initial products in the formation of excited OH molecules will increase. However, there is very little information at the present on the hydroxyl emission of high latitudes, and the available information refers mainly to single measurements of the rotational temperature [2, 6-8].

This article presents the results of spectroscopic observations/23 of hydroxyl emission in an auroral zone (Loparskaya station,  $\phi = 68.3^\circ$ ), for the winter months of 1960-1963.

### Apparatus

The spectra were photographed on the standard spectrographs SP-48 (for the visible region) and SP-50 (for the infrared) [10]. For the receivers of the infrared emission in the spectrographs SP-50, we used highly-sensitive multi-stage image converter tubes (ICT), which provided for shortening the exposure time by many times, in comparison with the single-stage converters of the type FKT-1. In article [11], there are definite indications of the ineffectiveness of multistage ICT's for spectroscopic observations, because of deterioration in the resolving power, the smaller dimensions of the operational field, and the high dark background. However, the practice of operations with multistage converters has shown that, on the same apparatus (spectrographs SP-50), we can obtain spectrograms which are no worse than those obtained from single-stage converters of the type FKT-1.

The dark background of multistage converters can be weakened rather effectively by cooling with dry ice; in any case, it does not appear during the time of the exposure, as we can see from examining the records of the spectra for airglow and aurorae, which are shown in Figure 1. A substantial disadvantage of multistage converters is the small field of the screen (less than  $1 \text{ cm}^2$ ), where the image is well focused. Thus, on a spectrograph SP-50, the focused region of the spectrum is roughly  $500 \text{ \AA}$ , while, on a FKT-1, it is  $\sim 900 \text{ \AA}$ . However, the losses in the region of the spectrum encompassed are completely compensated for by the gains in the exposure of the spectra, which is very essential in studying the emissions which change with time. A two-stage converter gives, in comparison with a one-stage converter, amplification by more than one order, while a three-stage converter gives amplification by more

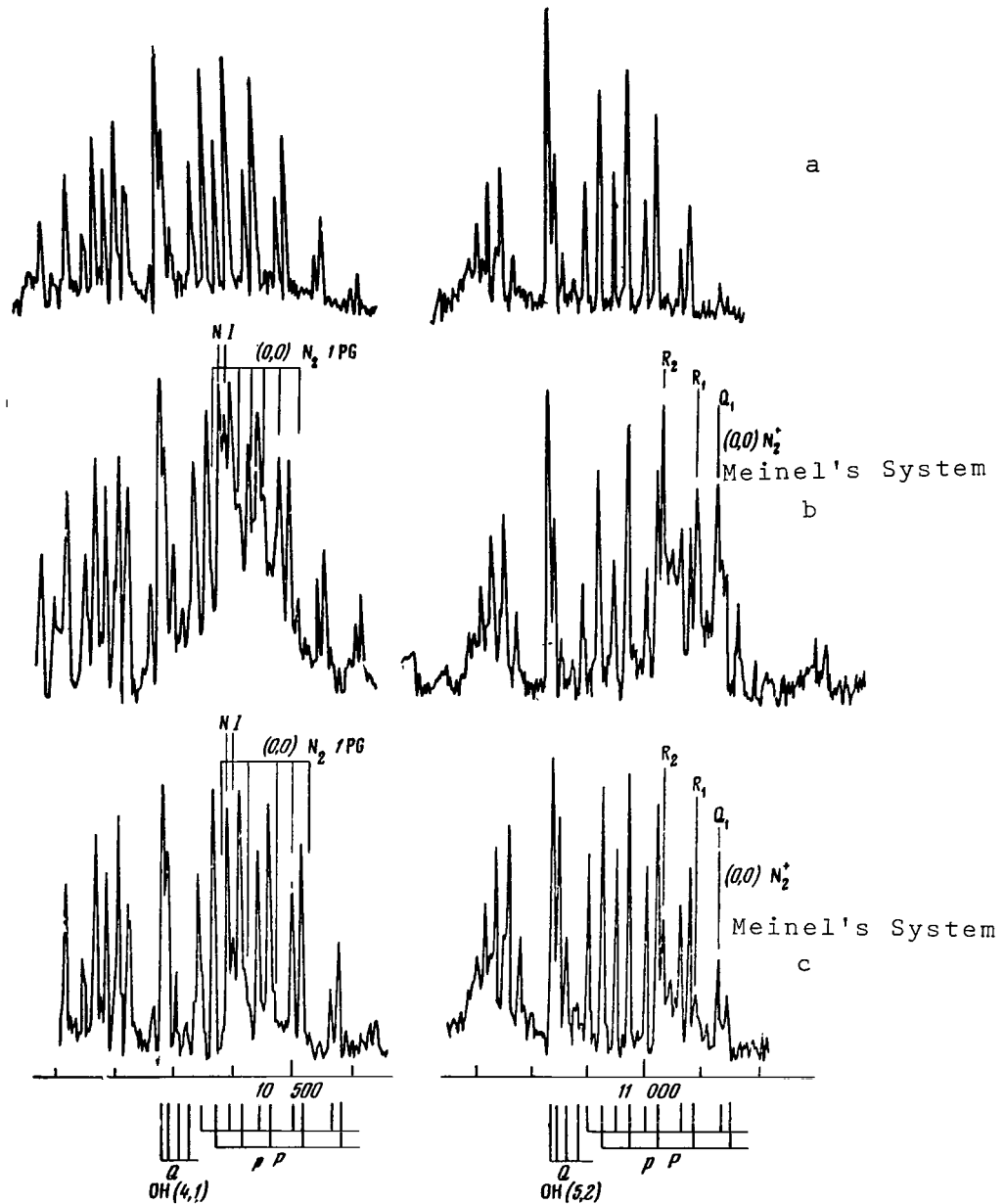


Fig. 1. Records of the OH Bands (4.1) and (5.2) Obtained in a Pure Night Sky (a), During very Intense Aurorae, Scale-Number Three-Four (b), and During Weak Aurorae (c).

than two orders (generally speaking, a three-stage converter should give amplification by four or five orders, but, in practice, it is difficult to achieve such a value; it is relatively easy to obtain an amplification of 100 times).

We had some apprehensions in relation to the fact that the sensitivity of the ICT might decrease when the anode was cooled off to a great degree [11]. However, the use of the apparatus in the open air at the Loparskaya station, where the temperature in the winter frequently reached  $-45^{\circ}$  C, showed that the cooling of the anode does not affect the sensitivity of the apparatus. A special test made by cooling the anode of the converter with dry ice ( $T = -78^{\circ}$  C) also showed no decrease in the sensitivity of the ICT.

The multistage converters, in addition to their higher sensitivity, also have the advantage that they can operate in open air under any atmospheric conditions (low temperature, high humidity). This is important, for example, in studying aurorae, when it is necessary to trace the luminous formation. In working with photo-contact tubes with photographic recording, it is necessary to apply special methods in order to dry the anode (e.g., by electrical heating); otherwise, with an increase in the humidity in the space between the anode and the film, there are multiple electrical charges which spoil the spectra. The charges necessarily appear during an increase in the temperature of the surrounding air, since the anode is cooler, and, therefore, the water vapor is condensed on it (the anode space in a FKT-1 cannot be pressurized, since the tape is fastened directly at the anode, without reversible optics).

### Results of the Measurements

In studying the hydroxyl emission at high latitudes, it is of /25 primary interest to compare the absolute intensity and the rotational temperature of the OH bands with their values at lower latitudes. Despite the fact that the observations of the OH emission are conducted at stations in the Soviet Union [3, 5, 9, 12] on the same type of apparatus [10], the sensitivities of the instruments were not comparable with the general photometric etalon. Therefore, there could be some disagreements related to the different methods of calibration in absolute units in the estimates of absolute OH intensity. Therefore, we made an absolute calibration of the spectra by the green line in exactly the same way as we did previously [13]. In this case, the relative calibration of the spectra was made by the etalon tube ( $T_K = 2750^{\circ}$  K), and in order to join it to the absolute units by the series with the first sequence of the hydroxyl spectrum in the region of 10,000-12,000 Å, we photographed the green line in the second sequence, for which the slit of the spectrograph was divided into fields by the same filters as were used at the Byurakanskaya Observatory: ZS-18 and IKS-13. The photographing was made through these filters, with an etalon tube having an exposure equal to that for obtaining the spectra of the night sky.

Then, during certain nights with good transmissivity and without any visible forms of aurorae, we photographed the spectra of the night sky at the zenith, and simultaneously measured the intensity of the green with the aid of the standard photometer of the IGY. This photometer was calibrated in absolute units, and was comparable to the etalon photometer of Roach [14].

TABLE 1. ABSOLUTE INTENSITY OF THE OH BAND (5.2), MEASURED BY THE INTENSITY OF THE GREEN LINE

Date	$I_{5577}$ , Rayleighs (measured by N.V. Dzhordzhio)	$I_{OH(5.2)}$ Rayleighs	Date	$I_{5577}$ , Rayleighs (measured by D.G. Taranova)	$I_{OH(5.2)}$ Rayleighs
21-22.II 1960	750	9800	25-26.II 1961	480	6300
22-23.II 1960	180	5500	13-14.III 1961	250	5900
25-26.II 1960	380	6100	18-19.III 1961	300	7600
27-28.II 1960	800	9100			
3-4. I 1960	180	1040			
$I_{av}(5.2)$		8200			6600

Table 1 shows the results of determining the intensity of the OH band (5.2) in the green, considering the transparency in the corresponding regions of the spectrum according to the data in [15]. The average intensity of the OH band (5.2), evaluated by the green line for a short observation period, was equal to 8200 Rayleighs in 1960 and to 6600 Rayleighs in 1961, which, within the limits of the variation in intensity of the hydroxyl emission and of the accuracy of the measurements, coincides with the average value for  $I(5.2)$  as 12,000 Rayleighs [13], which was obtained at the Byurakan-skaya Observatory in 1957. A similar result is obtained by the OH bands which are located within the visible region of the spectrum, 5000-6700 Å. We did not make quantitative evaluations of the intensity of the OH bands in this region, since the visible region, in an auroral zone, is frequently blended with strong bands of  $1PGN_2$ . However, on spectrographs of the same type, SP-48, and on an identical film  $D_N$  and A-700 at high-latitude stations, the photographs of the OH spectra were obtained, on the average, for the same exposure (5-10 hours) as those at southern [9, 12, 16] and middle latitudes [17]. Therefore, we can say that the intensity of the hydroxyl emission at high latitudes is not higher than that at middle latitudes. /26

#### Results of Determining the $T_{rot}$ (OH)

Inasmuch as, in the auroral zone where we conducted the observations, the visible and closer infrared regions are not very

suitable for a systematic examination of the hydroxyl emission (because of the overlapping of very intensive emissions of the aurorae), the principal results were obtained for the OH bands (4.1) and (5.2). Relatively weak bands are superimposed over them: (0.0) 1P<sub>GN</sub>2 in the first case, and the (0.0) band of the Meinel system, N<sub>2</sub>, in the second. By the OH band (5.2), we can evaluate the  $T_{rot}$  even during intensive aurorae by the three *P* lines and the three *p* lines. Figure 1 shows the "impurification" of the OH bands (4.1) and (5.2) with weak and intensive aurorae. The rotational temperature was determined by a refined formula for the energy of the rotational levels [18]. The error of a single measurement of the  $T_{rot}$  generally did not exceed  $\pm 10^\circ$ . However, there were some cases when the error reached  $\pm 20^\circ$  and more, even for the spectra which had high optical density and which were well focused. Such an error is found in a number of authors [1, 4, 6, and others].

Such a great error can be explained, not only by defects in the apparatus and the photographs, but also, to a much greater degree, by distortions of the contour of the *P*-branch by multiple lines and bands for absorption of water vapor and oxygen, and by Fraunhofer absorption lines in the superimposed spectrum of the stellar and zodiacal light, as well as by an inaccurate calculation for the continuum. During disadvantageous atmospheric conditions, the distortions of the contour of the *P*-branch are so great that they are immediately obvious in examining the spectrograms. For example, there are sometimes found the anomalously intensified lines *P*<sub>2</sub>, in the OH band (5.2), and *P*<sub>5</sub>, in the OH band (7.3), since they are located in those segments of the spectrum which are relatively free of absorption. The line *P*<sub>3</sub> in the OH band (8.4), on the other hand, coincides with one of the lines of the band for absorption of water vapor  $\rho\sigma\tau$ , and, therefore, it is very weakened when the atmosphere is not very transparent. To a greater or lesser degree, the other OH bands are also distorted by the bands of absorption. Therefore it could be that the substantial differences which are observed in determining the  $T_{rot}$  from the bands with higher and lower original levels (in the first case,  $T_{rot}$  is higher than in the second [3, 5]), can be explained, not only by the physical nature of the hydroxyl emission [19-21], but also by various atmospheric distortions of the OH bands located in different regions of the spectrum. For this reason, obviously, it would be more correct to draw conclusions on the seasonal, diurnal, and other variations of the  $T_{rot}$  of OH according to systematic observations of one band, than according to observations of different bands at various periods of time, since the same OH band must be more or less identically distorted under the same atmospheric conditions. For such a band, we selected the OH band (5.2), which, as we said earlier, is the least distorted by the aurorae, and therefore is suitable for regular observations of the hydroxyl emission in an auroral zone.

Figure 2 shows the seasonal variations of the rotational OH temperature determined according to the band (5.2).

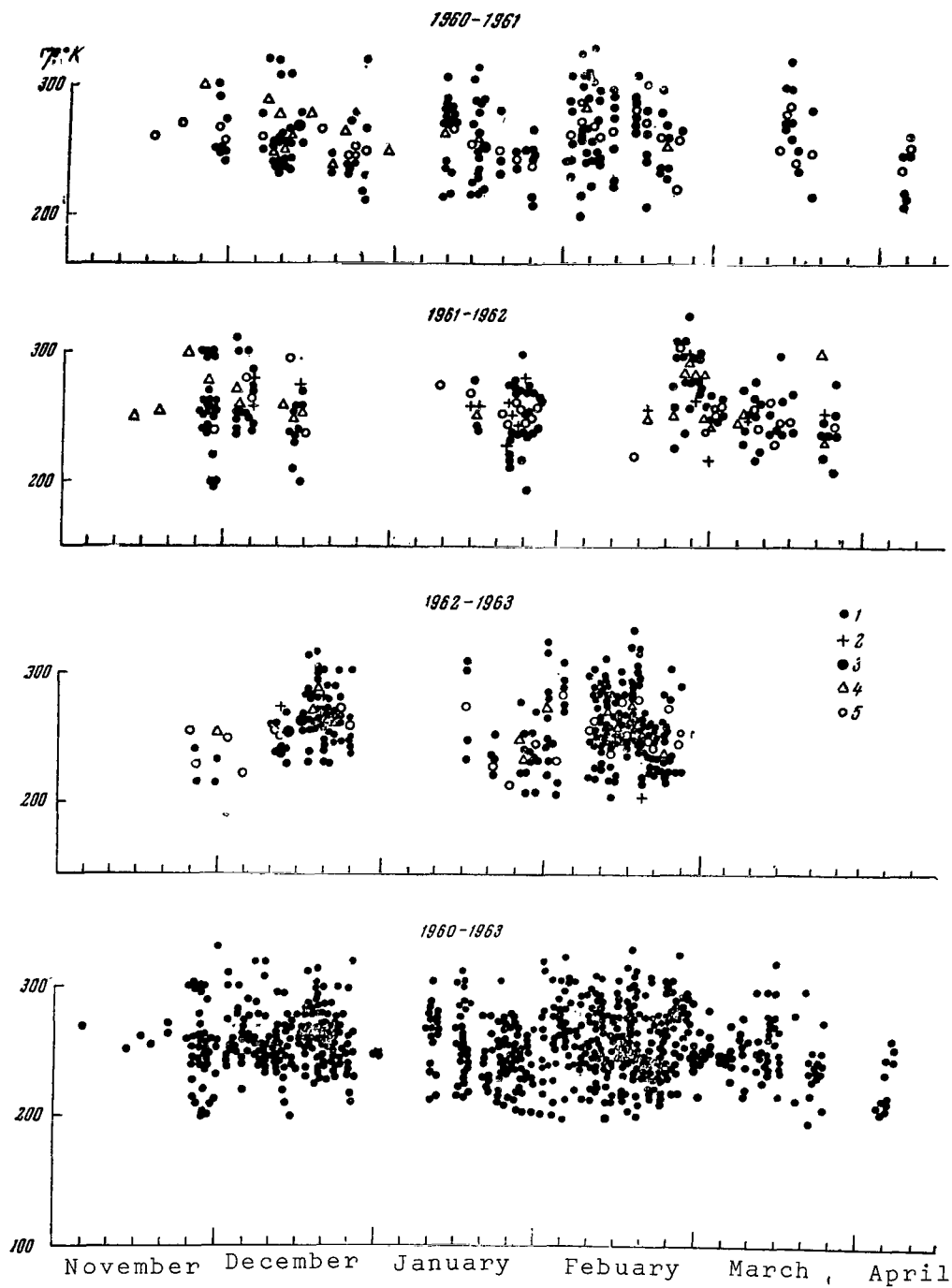


Fig. 2. Seasonal Variation of the Rotational Temperature According to the OH Band (5.2). (1) The Value of  $T_{rot}$  for the Course of One Night; (2)  $T_{rot}$  for an Observation in the Direction of the Milky Way; (3)  $T_{rot}$  as an Average Value for the Night Sky; (4) The Average  $T_{rot}$  during Very Intensive Aurorae; (5) The Average  $T_{rot}$  during Weak Aurorae.

According to our observations, no seasonal variation of the  $T_{\text{rot}}$  (OH) is found. It is possible that this could be explained by the limited period of the observations - from November to March. According to the data of other stations, there are observed maximally high temperature and intensity of the hydroxyl emission during the winter period.

Recently, there have appeared, in the literature (e.g., [22] and others), concepts on the radar-observation lines of absorption of interstellar hydroxyl. In relation to this, we had apprehensions that the existing emission of the interstellar hydroxyl in our spectral region could possibly affect the results of the observations of the winter hydroxyl emission. However, we can see from Figures 2 to 4 that no effect of the possible emission of the interstellar hydroxyl is found.

TABLE 2. COMPARISON OF SIMULTANEOUS OBSERVATIONS OF THE  $T_{\text{rot}}$  OF OH AT VARIOUS LATITUDES

Observation Period	Avg. $T_{\text{rot}}$ of OH During Observation Period, °K	Observation Period	Avg. $T_{\text{rot}}$ of OH during Observation Period, °K
23.I 1960- 4.IV 1960	264 ± 26	12.XI 1961- 25.III 1962	259 ± 19
13.XI 1960- 6. IV 1961	265 ± 23	23.XI 1962- 25.II 1963	262 ± 21

Figure 2 shows average values of  $T_{\text{rot}}$  for one night, which is not very demonstrative, since the temperature changes from night to night, and these variations sometimes reach several tens of degrees. But we wanted to isolate the nights with aurorae, and, moreover, the observations in the direction toward the Milky Way.

In order to obtain a smoother seasonal running of the temperature, and, thus, a more demonstrative one, it would have been necessary to average the values of  $T_{\text{rot}}$  for a longer period. The last graph of Figure 2 shows all the results for four periods of observations, averaged for five-day intervals. But, with such a great amount of averaging, there is no seasonal variation of the  $T_{\text{rot}}$  (OH) found during the winter months. The average temperature per season does not change greatly from year to year, as can be seen from Table 2, and there is no decrease observed in the rotational temperature of OH during the years of minimum solar activity. During the periods of active aurorae (March-April), there is no increase observed in the  $T_{\text{rot}}$ . Moreover, the rotational temperature and the intensity of the OH bands do not increase, either at the moment of the aurora, or after the disappearance of its clear forms (see Fig. 2 and 3). A similar result was obtained for the OH band (6.2)



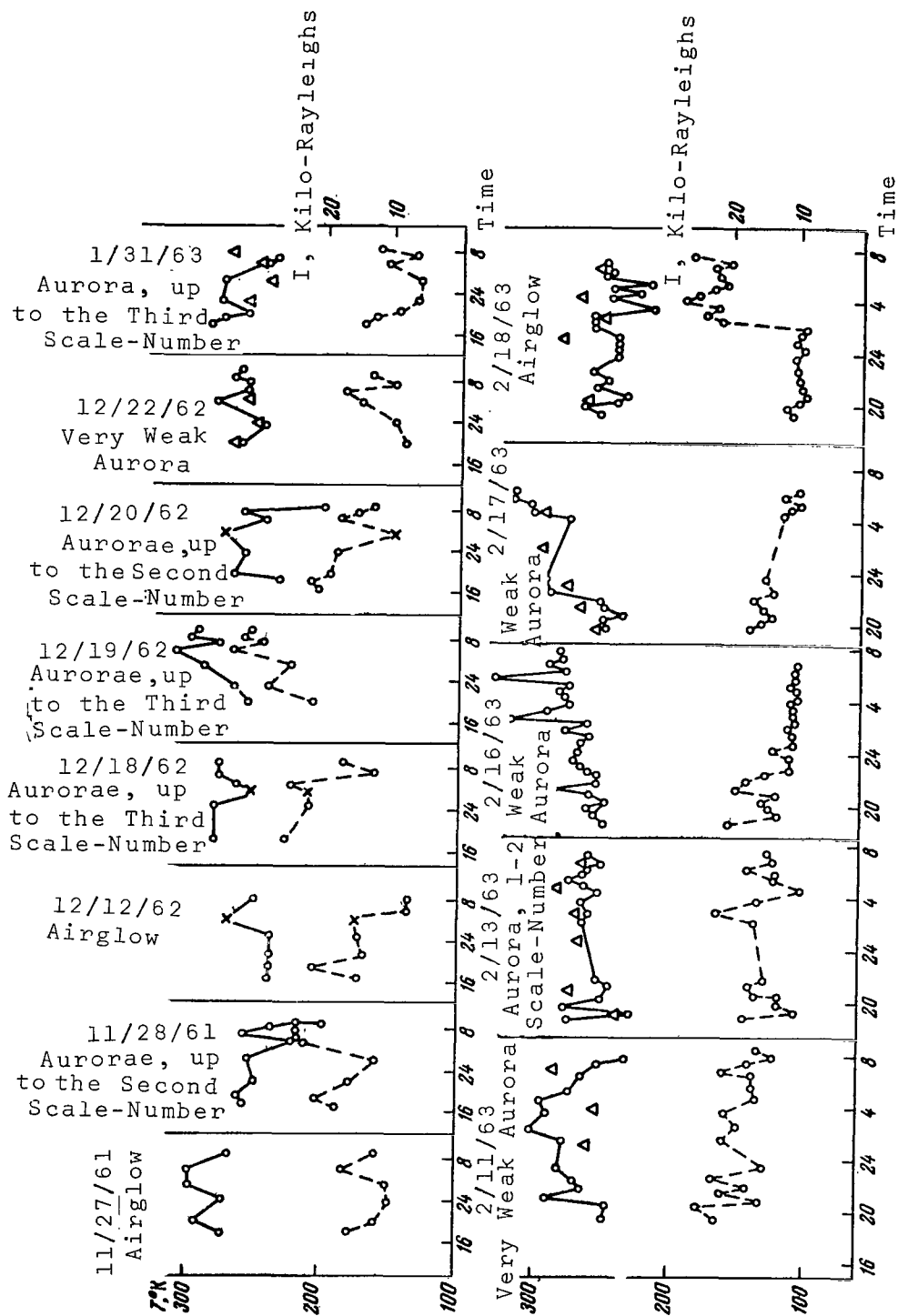


Fig. 3. Daily Variation of the Temperature and the Intensity of the Band (5.2), According to Observations at Different Days.

[23]. For this band, during the aurorae, the emission of elemental oxygen  $\lambda$  8446 Å is superimposed. This, however, can easily be excluded with a fairly good spectral resolution [23]. During an intensive geomagnetic excitation, there is observed an increase in the temperature, as well as a decrease in the intensity, for the OH bands (9.3) and (6.1) [4]. It seems to us that, in the given case, the increase in the temperature can be explained by the superposition of the emission for the  $1\text{PGN}_2$  bands, which could "illuminate" the outermost weakest lines of the P-branch in the OH band, and thereby cause a seeming increase in the temperature.

It follows from our observations that the rotational OH temperature does not increase during aurorae, although it has now been definitely established that, during aurorae and geomagnetic excitations, intensive fluxes, which, at altitudes higher than 150 km, cause the atmosphere to heat up, invade the Earth's atmosphere at high latitudes [24, 25]. But the energy of these fluxes is obviously not sufficient for denser layers of the atmosphere, on the level of the hydroxyl emission (70-90 km [26, 27]) to heat up, because of the short time for their effect. And since the high latitudes were subjected to the continuous effect of the solar wind, we can expect that, at high latitudes, the temperature of the lowest layers of the upper atmosphere (70-100 km) is, on the average, higher than /30

TABLE 3. VARIATIONS OF THE ROTATIONAL TEMPERATURE OF THE OH BANDS FROM YEAR TO YEAR

Date	$T(5.2), ^\circ\text{K}$ (Loparskaya, $\phi=68^\circ$ )	$T(5.2), ^\circ\text{K}$ (Zvenigorod, $\phi=56^\circ$ )	Date	$T(5.2), ^\circ\text{K}$ (Loparskaya, $\phi=68^\circ$ )	$T(6.1), ^\circ\text{K}$ (Abastumani, $\phi=42^\circ$ )	Noxon's Measurements of $T_{\text{rot}}$ during a flight at various latitudes	
						$\phi$	$T(5.3)$
19.I 1961	250±15	298	27.I 1960	288	234	21.III 1963	
25.I 1961	239±27	217	27.II 1960	260	301	55-62	195±16
29.III 1961	221±7	195	25.XI 1960	287	269	62-69	215±15
5.I 1961	262±6	182	8.XII 1960	250	264	69-77	170±15
29.XII 1961	240±10	235	9.XII 1960	277	296	77-85	160±15
22.I 1962	247±14	236	10.XII 1960	250	285	10.III 1964	
24.II 1962	253±10	252	11.XII 1960	263	213	55-69	210±25
25.II 1962	286±14	206				69-85	185±25
26.II 1962	281±11	234				20.I 1964	
27.II 1962	251±8	269				10-20	275±35
28.II 1962	247±18	232					
1.III 1962	253±3	240					
9.III 1962	244±19	195					
21.III 1962	232	198					
3.I 1962	213	188					
4.I 1962	216	173					
$T_{\text{av}}$	245±14	222±28		268±16	266±26		

at lower latitudes. Therefore, it is of definite interest to compare the  $T_{\text{rot}}$  (OH) for higher and lower latitudes. Such comparisons have already been made [1,2,6,7,25,26]. They showed a significant increase in the  $T_{\text{rot}}$  at high latitudes. However, in this case, the data used for the high latitudes were obtained as a result of single measurements of the rotational temperature.

Moreover, the authors compared temperatures which were determined by spectra obtained on different apparatus, during different times, and from different bands. But since the rotational temperature undergoes significant seasonal and diurnal variations, and, moreover, the rotational temperature of different bands can vary [3,5,18,20], a comparison of the non-uniform materials cannot give a reliable representation of the relationship between the value of the rotational temperature and the latitude of the observation site. It is possible that the various results which were obtained in comparing the  $T_{\text{rot}}$  at middle latitudes (40-55°N) could be explained by the non-uniformity of the materials being compared.

The results of simultaneous measurements of the  $T_{\text{rot}}$  at other latitudes were compared in [28]. Table 3 shows a comparison of the measurements of the  $T_{\text{rot}}$  at Loparskaya ( $\phi = 68^\circ\text{N}$ ) with the simultaneous measurements of the  $T_{\text{rot}}$  in Zvenigorod ( $\phi = 56^\circ\text{N}$ ) of OH at the Loparskaya station was almost always higher than that at the Zvenigorod station. A comparison of the rotational temperatures for various bands [ $T(5.2)$  Loparskaya, and  $T(6.1)$ , Abastumani] did not give a definite result, while the average temperatures at these stations were roughly identical ( $268 \pm 16$  and  $266 \pm 26^\circ\text{K}$ , respectively). The average temperature per total days of observation at the Loparskaya station ( $245 \pm 14^\circ\text{K}$ ) was higher than the  $T_{\text{rot}}$  /31 at Zvenigorod ( $222 \pm 28^\circ\text{K}$ ) by roughly  $20^\circ\text{K}$ . The divergence from the average value of the temperature of the Loparskaya temperature was less than for Zvenigorod and Abastumani. This is probably related to the fact that, for the Loparskaya station, the average temperatures per night were given, since a more sensitive apparatus was used here, which provided for obtaining several photographs of the hydroxyl spectra, while, in Zvenigorod and Abastumani, there was only one photograph of the spectrum per night.

The meteorological conditions at the various stations which conducted simultaneous observations were also unlike. Therefore, we compared the temperatures which were averaged for a long period of observation. The  $T_{\text{rot}}$  for the OH band (5.2) during the period from January 21, 1960 to February 20, 1963, at the Loparskaya station was equal to  $255 \pm 6^\circ\text{K}$ , while at the Zvenigorod station, from October 17, 1960 to March 21, 1962, it was equal to  $214 \pm 21^\circ\text{K}$ .

Thus, our determinations of the  $T_{\text{rot}}$  (OH) for a long period of observations (1960-1963) show that, at a latitude of  $68^\circ\text{N}$ , the rotational temperature is higher than at a latitude of  $56^\circ\text{N}$ , although insignificantly, by  $20-40^\circ\text{K}$ . The earliest observations [2, 6, 7] showed a greater difference in the temperatures - on the order of  $100^\circ\text{K}$ .

Noxon's measurements [8] during flights over latitudes of 55-85°N (these measurements are also shown in Table 3) show a decrease in the  $T_{rot}$  with an increase in the latitude, which contradicts all the data we have. Noxon determined the  $T_{rot}$  by the synthetic contour of the OH band (5.3), since this band was not resolved with his apparatus. The error in the measurement was  $\pm 15^\circ$  K, which, however, was scarcely probable. Obviously, this is much greater than the errors for measuring the  $T_{rot}$  by the bands with a well-resolved rotational structure, which, as a rule, did not exceed  $\pm 10^\circ$  K, but was more often on the order of  $\pm 5^\circ$  K [1, 3, 5]. The rotational temperatures obtained by the synthetic contour always surprisingly "coincided" with one another [29, 30], if, for such an accuracy in measurements, we can speak of a good coincidence, but they differed from the measurements of the  $T_{rot}$  with a good resolution [2, 25].

It is completely obvious that the non-resolved OH bands are not suitable for determining the rotational temperature, since, for such bands, the  $T_{rot}$  is calculated with a large error comprising no less than  $\pm 50^\circ$  K [29, 30]. This is not admissible for finding a number of rules in the behavior of the rotational temperature. For example, in order to find a relationship between the rotational temperature and the number of the upper oscillational level, it is necessary to determine the  $T_{rot}$  with a much higher accuracy than occurs for the bands with a non-resolved rotational structure, since the change in the  $T_{rot}$  with the change of  $\nu'$  per unit, according to the observations of Shefov [3] and Yarin [5], averages only several degrees.

The discovery of a relationship between the rotational temperature and the number of the vibrational level is of important geophysical value, since it shows the appearance of the hydroxyl emission in separate elementary layers at various temperatures [18, 20]. Table 4 gives a comparison between the  $T_{rot}$  of the OH bands and various values of  $\nu'$ . For the comparison, we selected the spectra which were obtained during fair weather and without aurorae, which was determined by the lack of traces of the (1.0) band of Meinel  $N_2^+ \lambda 9200 \text{ \AA}$  - the most intensive emission of the aurorae in the nearest infrared region. The OH band (7.3) was obtained on a less sensitive ICT than the OH bands (4.1) and (5.2). Therefore, for one night, we obtained one or two spectra of the OH band (7.3) with an exposure of 3-5 hours, and several spectra of the OH bands (4.1) and (5.2). For the OH bands (4.1) and (5.2), the table shows the average temperature per night and the average divergence. The error in determining the  $T_{rot}$  averaged  $\pm 5^\circ$  K, and did not exceed  $\pm 10^\circ$  K (without considering the spectral transmissivity of the atmosphere). According to our observations, there is no relationship found between  $T_{rot}$  and  $\nu'$ . However, we still cannot draw any definitive conclusions on the relationship between the temperature and the number of the vibrational level, since more accurate determinations of the temperature, considering the spectral transmissivity of the atmosphere, are necessary. In the literature, in relation to the

dependence of  $T_{rot}$  on  $\nu'$ , there is very inconsistent information. For the majority of the authors, there is no difference observed in the temperatures of the bands with various  $\nu'$ , within the limits of measurement errors [1,9,16,31,32].

TABLE 4. RELATIONSHIP BETWEEN THE  $T_{rot}$  OF OH AND THE NUMBER OF THE UPPERMOST VIBRATIONAL LEVEL

Date	Band		
	(4,1)	(5,2)	(7,3)
23-24.I 1962		263±17	280±3
2-3.III 1962		260±3	255±25
8-9.III 1962		259±14	240±5
9-10.III 1962		243±23	222±10
13-14.III 1962		248±11	245±3
23-24.III 1962		245±21	226±5
22-23.XII 1962	256±6	262±8	258±11
25-26.XII 1962	252±15	258±17	248±8
14-15.II 1963	274±20	271±15	275±10
19-20.II 1963	262±12	244±8	275±8
20-21.II 1963	252±20	237±17	240±5
$T_{rot}$ (average)	259	254	251

The relationship between the rotational temperature and the intensity of the corresponding bands has also been studied very little. As we already said, the data now available on the relationship between  $I$  (OH) and  $T_{rot}$  are rather contradictory [5, 3, 9], although, obviously, the observations of Yarin [5] show that, with an increase in the latitude, the relationship between  $I$  (OH) and  $T_{rot}$  is intensified. Therefore, we assumed that, at even higher latitudes, the relationship between  $I$  (OH) and  $T_{rot}$  must appear even more clearly. The latitudinal difference in the behavior of the hydroxyl emission can show the presence of certain mechanisms for excitation of the OH emission, while the intensification of the relationship between  $I$  (OH) and  $T_{rot}$  with an increase in the latitude can show the predominance of an azone-hydrogen mechanism of excitation at higher latitudes. However, we could never draw such a conclusion from our observations.

Figure 4 shows the relationship between  $I$  (OH) and  $T_{rot}$  for the OH band (5.2) at the Loparskaya station, as the results of the observations in 1960-1963. In order to construct the graph, we used the average values of  $I$  (OH) and  $T_{rot}$  per night. In this case, we took almost all the results of the observations, including those obtained during rather inclement weather, since there were not very many clear nights. However, strictly speaking, we should not do this, particularly in relation to determining the intensity. There-

fore, the conclusion obtained on the lack of a relationship between  $I(\text{OH})$  and  $T_{\text{rot}}$  cannot be determinant.

An examination of the relationship between the intensity and the temperature during a night with good transparency was more convincing. Certain results of this are shown in Figure 3. We can see from this figure that there is no definite relationship between  $I(\text{OH})$  and  $T_{\text{rot}}$ , and that, during different nights, there are very

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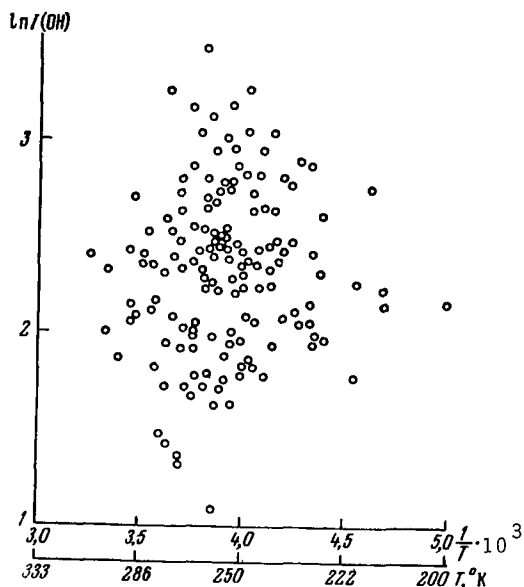


Fig. 4. The Relationship Between Intensity and Rotational Temperature of the OH Band (5.2), According to the Results of Observations from 1960 to 1963.

different variations of the intensity and the temperature, which can reach several tens of percents and several tens of degrees, respectively (see Figs. 2 and 3). Such great changes in the intensity and the temperature during a relatively brief time, obviously, cannot show the real change of the temperature of the layer at altitudes of 70-90 km, and is probably related to the intensive vertical displacement of the atmosphere at these altitudes, which has been mentioned several times [20-22].

Ballis and Venkateswaran [33] showed that a dependence on the concentrations of  $n(\text{O})$ ,  $n(\text{H})$ , and  $n(\text{O}_3)$  in the case of an ozone-hydrogen mechanism for the OH excitations, can be found in different time variations of the intensity of hydroxyl emission: the maximum or the minimum

during the middle of the night, an increase in the intensity during the morning or evening. In the case of an oxygen-hydrogen mechanism for excitation, there should be observed a continuous decrease in the OH intensity during the course of the night. Our observations of the hydroxyl emission show the variability in types of time-variations of the OH intensity (other authors also observed a similar nature in the time-variations of  $I(\text{OH})$  [5, 9]. However, the lack of a relationship between  $I(\text{OH})$  and  $T_{\text{rot}}$  does not provide for giving preference to any one excitation mechanism. It is most probable that several mechanisms, which also cause the complex picture of the hydroxyl emission, take part in the formation of the excited OH molecules. A number of variations in the mechanisms for the OH excitation, in addition to the well-known ozone-hydrogen [34, 35] and oxygen-hydrogen [36] ones, were suggested [20, 21, 37] in relation to the fact that recent measurements conducted from rockets

[38] showed that the concentration of atomic hydrogen in the upper atmosphere is two-three orders less than that required for maintaining the OH intensity observed as a result of the reaction  $O_3-H$  or  $O_2-H$ .

### Conclusion

(1) Within the limits of accuracy for the absolute calibration of the apparatus up to several tenths of percents, the intensity of the hydroxyl emission at high latitudes does not differ greatly from the OH intensity at lower latitudes.

(2) During aurorae, the OH intensity does not increase. The  $I(OH)$  also does not increase during the period of the maximum activity of the aurorae (March-April).

(3) The rotational temperature of the OH bands was higher at the Loparskaya station than at lower latitudes, but not by much. When the latitude increases from  $56^\circ N$  (Zvenigorod) to  $68^\circ N$  (Loparskaya), the  $T_{rot}$  increases by  $20-40^\circ K$ . /34

(4) Just as the intensity of the hydroxyl emission, the rotational temperature during aurorae and after the disappearance of their clear forms, does not increase. During the period of active aurorae (March-April), the  $T_{rot}$  also does not increase.

(5) There was no seasonal variation of the  $I(OH)$  and  $T_{rot}$  found. It is possible that this is related to the limited period of observations (November-March).

(6) The rotational temperature during the winter months remains almost unchanged from year to year, and no decrease in the  $T_{OH}$  is observed during the years when the solar activity is low.

(7) For high latitudes, there is no relationship found between the intensity and the rotational temperature of OH.

(8) Within the range of measurement error, there is no relationship found between the temperature and the number of the upper vibrational level.

(9) The rotational temperature and the intensity of the hydroxyl emission undergo different variations during the course of a night. The variations in temperature from night to night and during one night can reach several tens of degrees, while the variations in intensity can reach several tens of percents.

It is possible that, in order to find any regularities in the OH emission, more precise measurements of the  $T_{rot}$  and  $I(OH)$  are necessary, in comparison to the measurements we now have (the errors in determining the intensity sometimes reach several tens of percents, while for the temperature, they sometimes reach several tens of

degrees). The apparatus now used for obtaining the OH spectra in the region from 5000 to 12,000 Å have completely sufficient resolution for obtaining the spectra with well-resolved rotational structures, but they have insufficient sensitivity for obtaining the OH spectra with a brief exposure. The OH spectra are usually obtained in 5-10 hours [4,6,12,16]. In such a long time, the transmissivity of the atmosphere and the sensitivity of the apparatus can change substantially (e.g., for an ICT, as a result of a change in the supply regime, and, for the films, as a result of a change in the temperature of the air).

We now have apparatus, with the aid of which we can obtain OH spectra with a rather brief exposure. Thus, with the aid of the spectroelectrophotometer DFS-14, the recording of OH bands such as (4.1) and (5.2) can be obtained in 5 min [39]. With the aid of a three-stage image converter tube with the same brief exposure, we can obtain weaker infrared bands on the spectrograph SP-50.

In analyzing the spectra of hydroxyl, it is necessary to consider the spectral transmissivity of the atmosphere. There is important, both in measuring the intensity, and in determining the temperature. In the range of temperatures from 200 to 300° K, which are usually obtained by the spectra of the hydroxyl emission, there are observed only five or six lines in the *P*-branch, while the intensity of the lines, beginning with  $P_3$ , decreases rapidly, so that, for a normal blackening of the lines  $P_1$ - $P_3$ , the lines  $P_4$  and (in particular)  $P_5$  and  $P_6$  do not have a great intensity (see Fig. 1). For these lines, the photometric errors are great, and the atmospheric distortions are seen clearly in their intensities (impurification by other emissions or weakening by absorption bands). Their "short exposure" leads to a significant increase in the temperature, by 10-20° K and even more, while an insignificant weakening during cloudy weather leads to a decrease in the temperature by the same order [e.g., in the OH bands (4.1) and (5.2)].

Therefore, it is necessary to perfect the method for analyzing the OH spectra: to check the determination of the temperature and the intensity, for each band, under certain meteorological conditions. /35

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